Safety Analysis of the Molten Salt Fast Reactor Fuel Composition using Moltres

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ABSTRACT

Molten Salt Reactors (MSRs) potentially possess the ability to run for extended periods with minimal shutdown time due to online fuel reprocessing. Their proposed equilibrium fuel compositions differ substantially from start-up compositions due to burnup of initial fissile material and breeding of new fissile material, but also fissile material feeds and removal of fission products. Since the changing fuel composition impacts safety parameters (e.g. reactivity feedback coefficients), a licensing case for this class of reactors must fully characterize those impacts.

Numerous computational tools exist for conventional nuclear reactors, but MSRs present unique computational challenges that many fail to address effectively. MSRs differ profoundly from conventional solid-fuelled reactors, particularly in their neutronics and thermal-hydraulics behaviors. New MSR simulation tools must capture strong coupling between neutronics and thermal-hydraulics exhibited by delayed neutron precursor movement as well as strong Doppler and density feedback in the fuel salt. This paper investigates the impact of changing fuel composition on safety parameters in the Molten Salt Fast Reactor (MSFR) using a new simulation tool for MSRs, Moltres.[1]

Moltres is an open source coupled neutronics/thermal hydraulics simulation application for simulating MSRs. Built on the Multiphysics Object-Oriented Simulation Environment (MOOSE) finite element framework,[2] Moltres solves the coupled time-dependent multi-group neutron diffusion, temperature, and delayed neutron precursor (DNP) governing equations. The temperature and DNP equations fully account for fuel advection as the fuel salt flows upwards through the core.

The MSFR model studied in this paper,[3] is a reference design for a fast-spectrum MSR developed under the Evaluation and Viability of Liquid Fuel Fast Reactor System (EVOL) and Safety Assessment of the Molten Salt Fast Reactor (SAMOFAR) projects.[4] The full paper will present results from Moltres simulation of the MSFR reference model with three fuel compositions: start-up, early life, and equilibrium.

In line with the purpose of the MSFR as a thorium breeder, its chosen start-up fuel composition is a eutectic mixture of ^{233}U and ^{232}Th fluorides in a lithium fluoride molten salt.[3] We generate group constants for each fuel composition using Serpent,[5] a continuous-energy Monte Carlo code for numerous reactor physics applications. For verification, we will compare group constants and reactivity coefficients with existing data[6,7] of safety parameters for the three fuel compositions. Using these group constants (χ, $\nu\Sigma_f$, $\Sigma_{g\to g'}$, $\frac{d\rho}{dT}$, etc.), Moltres then solves for the flux and temperature based on the neutron diffusion equation coupled with navier stokes thermal hydraulics. Transient simulations will establish the spatial distribution of flux, $\phi_g(\vec{r})$ and temperature, $T(\vec{r})$ during transients. These distributions will give insight into MSFR transient behavior, which will help us identify potential safety risks. These risks may warrant further study and possibly, changes to the fuel composition or the online fuel reprocessing scheme.

REFERENCES

1. A. LINDSAY, G. RIDLEY, A. RYKHLEVSKII, and K. HUFF, "Introduction to Moltres: An application for simulation of Molten Salt Reactors," *Annals of Nuclear Energy*, **114**, 530–540 (Apr. 2018).
2. D. GASTON, C. NEWMAN, G. HANSEN, and D. LEBRUN-GRANDIE, "MOOSE: A parallel computational framework for coupled systems of nonlinear equations," *Nuclear Engineering and Design*, **239**, *10*, 1768–1778 (Oct. 2009).
3. E. MERLE-LUCOTTE, D. HEUER, M. ALLIBERT, M. BROVCHENKO, N. CAPELLAN, and V. GHETTA, "Launching the thorium fuel cycle with the Molten Salt Fast Reactor," in "Proceedings of ICAPP," (2011), pp. 2–5.
4. J. SERP, M. ALLIBERT, O. BENES, S. DELPECH, O. FEYNBERG, V. GHETTA, D. HEUER, D. HOLCOMB, V. IGNATIEV, J. L. KLOOSTERMAN, L. LUZZI, E. MERLE-LUCOTTE, J. UHLÃŊÅŹ, R. YOSHIOKA, and D. ZHIMIN, "The molten salt reactor (MSR) in generation IV: Overview and perspectives," *Progress in Nuclear Energy*, **77**, *Supplement C*, 308–319 (Nov. 2014).
5. J. LEPPANEN, M. PUSA, T. VIITANEN, V. VALTAVIRTA, and T. KALTIAISENAHO, "The Serpent Monte Carlo code: Status, development and applications in 2013," *Annals of Nuclear Energy*, **82**, 142–150 (Aug. 2015).
6. C. FIORINA, M. AUFIERO, A. CAMMI, C. GUERRIERI, J. KREPEL, L. LUZZI, K. MIKITYUK, and M. E. RICOTTI, "Analysis of the MSFR Core Neutronics Adopting Different Neutron Transport Models," pp. 219–228 (Jul. 2012).
7. C. FIORINA, M. AUFIERO, A. CAMMI, F. FRANCESCHINI, J. KREPEL, L. LUZZI, K. MIKITYUK, and M. E. RICOTTI, "Investigation of the MSFR core physics and fuel cycle characteristics," *Progress in Nuclear Energy*, **68**, 153–168 (Sep. 2013).